Lava Eruption and Emplacement: Using Clues from Hawaii and Iceland to Probe the Lunar Past. D. H. Needham[1], C. W. Hamilton[2], J. E. Bleacher[3], P. L. Whelley[3,4], K. E. Young[3,5], S. P. Scheidt[2], J. A. Richardson[3,4], S. S. Sutton[2]. [1]NASA MSFC, 320 Sparkman Dr., Huntsville, AL 35805, debra.m.hurwitz@nasa.gov, [2]LPL University of Arizona, [3]NASA GSFC, [4]USRA, [5]Jacobs Engineering Group.

Introduction: Investigating recent eruptions on Earth is crucial to improving understanding of relationships between eruption dynamics and final lava flow morphologies. In this study, we investigated eruptions in Holuhraun, Iceland, and Kilauea, Hawaii to gain insight into the lava dynamics near the source vent, the initiation of lava channels, and the origin of down-channel features. Insights are applied to Rima Bode on the lunar nearside to deduce the sequence of events that formed this lunar sinuous rille system.

These insights are crucial to correctly interpreting whether the volcanic features associated with Rima Bode directly relate to eruption conditions at the vent and, thus, can help us understand those eruption dynamics, or, alternatively, whether the features formed as a result of more localized influences on lava flow dynamics. For example, if the lava channel developed early in the eruption and was linked to pulses in vent activity, its morphology can be analyzed to interpret the flux and duration of the eruption. Conversely, if the lava channel initiated late in the eruption as the result of a catastrophic breaching of lava that had previously pooled within the vent [*e.g.*, 1], then the final channel morphology will not indicate eruption dynamics but rather local dynamics associated with that breach event. Distinguishing between these two scenarios is crucial for correctly interpreting the intensity and duration of volcanic history on the Moon.

Geology of Rima Bode: Rima Bode (Fig. 1) is located in SE Sinus Aestuum on the lunar nearside and is characterized by an elongate source vent (Fig. 2a) and two channel segments separated by a smooth plain 266 km^2 in area (Fig. 3a). The channel segments are 109 and 139 km long, 870 and 670 m wide, and 100 and 75 m deep, respectively, measured using Lunar Reconnaissance Orbiter Wide Angle Camera (LRO WAC) images, Kaguya Terrain Camera (TC) images, and Lunar Orbiter Laser Altimeter (LOLA) topography tracks. Vent depth varies from 160 to 500 m and has a volume of ~6 km^3, and the upper channel initiates at the northwestern rim of the vent (Fig. 2a). The down-channel smooth plain has a marginal ledge that encircles the entire feature (Fig. 3a, arrow). By studying recent terrestrial eruptions, we gain insight into (1) the origin of vent morphology with its variable depths, (2) the timing of initial channel formation, and (3) the origin of the down-channel plain.

Origin of the Vent and Channel: The 2014–2015 eruption at Holuhraun, Iceland provides an analog for

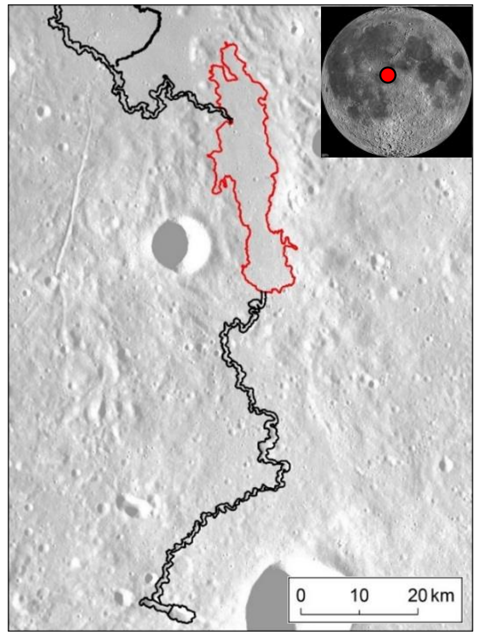

Fig. 1: Rima Bode (black line), in Sinus Aestuum on the lunar nearside (red dot in inset, WAC), seen with Kaguya TC data. The channel initiates at an elongate vent in the south and is separated into two segments by a mid-channel lava lake (red outline).

the vent/channel system of Rima Bode. This widely documented fissure eruption initiated August 29, 2014, and over the ensuing 183 days deposited ~1.5 km^3 of lava over an area of 83.5 km^2, with a mean eruption flux of 161 m^3/s [2]. The fissure developed spatter cones around distinct centers of explosive eruptions, with the largest cone encircling the longest-lived, 0.5 km-long northeastern cluster of eruption centers (Fig. 2b,c). Other sites of effusive activity ended earlier in the eruption (left part of Fig. 2b), leaving behind smaller cones and shallower pits after the eruption ceased.

Lava channels formed throughout the eruption—some were cut off by spatter deposition (*e.g.*, site of a once-active channel, white arrow in Fig. 2c) while others widened (*e.g.*, site of developing channel, black arrow in Fig. 2c), possibly through small-scale local erosion as lava carried portions of the cone down-channel. One channel in particular formed at the northeastern rim of the long-lived cone about half-way through the eruption, before the prominent cone had developed, then widened to form a prominent channel that remained active for the duration of the eruption. This channel was directly linked to the vent and, thus, its morphology reflects the dynamics of this eruption.

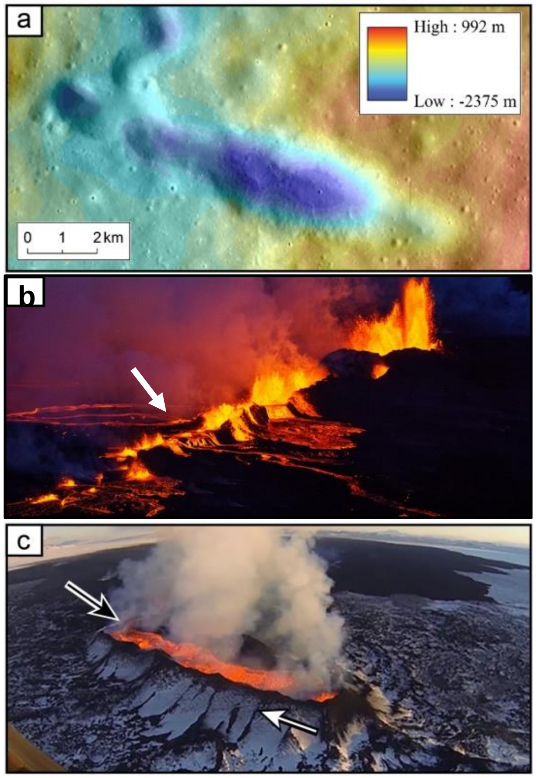

Fig. 2: (a) Rima Bode vent (LOLA on Kaguya TC), and the Holuhraun vent (b) late in 2014 with numerous channels later cut off by cinder deposition (white arrow, photo by Daði Harðarson ©Nýjar viddir) and (c) in February, 2015 (photo by Gísli Gíslason). The final Holuhraun vent has an associated channel (black arrow) similar to that seen at Rima Bode.

Origin of the Down-Channel Plain: The December, 1974 eruption at the West Rift of Kilauea, HI began at midnight on December 31, 1974 and lasted only 6 hours, depositing 0.014 km^3 over 7.5 km^2, with a mean eruption flux of 662 m^3/s. Although this eruption was much smaller than the eruptions at Holuhraun and at Rima Bode on the Moon, the resulting lava flow has a similar mid-channel feature to that observed at Rima Bode. The relatively smooth plain is characterized by crusted lava in the interior with three episodes of separation, and a marginal ledge of lava that denotes high lava stands 2–4 m above the plain floor (Fig. 3b). These observations are consistent with the formation of a lava lake that subsequently drained [2].

Similar ledges are observed around the smooth plain associated with Rima Bode (Fig. 3a), though these lunar ledges are 60–80 m above the adjacent plain. This suggests a lava lake similar to that observed in Hawaii also formed on the Moon, though at a much larger scale. The volume of the lunar lake provides an estimate for the volume of lava that erupted from the Rima Bode vent and flowed through the upper channel segment. This volume represents a minimum estimate because the lava may not have completely drained out of the channel or the lake, as is observed in the Hawaiian and Iceland lava channels.

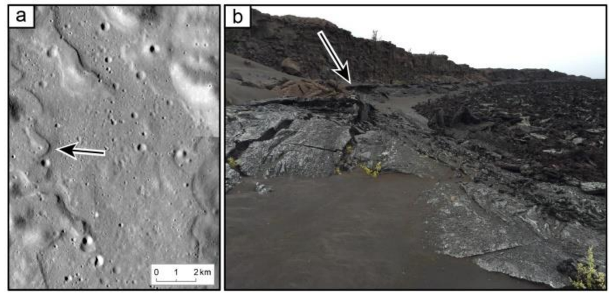

Fig. 3: (a) Rima Bode's central lake with marginal ledge, and (b) Kilauea, Hawaii, December, 1974 lava pond with marginal ledge.

Implications for Rima Bode: Rima Bode likely developed analogously to the terrestrial cases. Observed variations in eruption intensity along the Holuhraun fissure resulted in a final vent morphology with varied cone heights and vent depths, much like that seen in the elongate vent associated with Rima Bode. Additionally, observations of the well-developed lava channel that evolved over the duration of the Holuhraun eruption suggest that the Rima Bode channel likely also formed as a direct result of the eruption. Therefore, observed morphologies of the sinuous rille and the volume drained from the lava lake can be used to estimate the flux and duration of the Rima Bode eruption (Table 1).

Table 1: Flux and duration of three eruptions.

Eruption	Duration	Volume (km^3)	Flux (m^3/s)
December 1974	6 hours	0.014	662 (mean)
Holuhraun	183 days	1.6	161 (mean)
Rima Bode	10–22 days	14	7,000–16,000 (peak)

In an approach similar to that used in [3, 4], we used observed channel width and depth as well as lava lake volume as inputs to calculate the peak flux of the Rima Bode eruption to be between 7,000 and 16,000 m^3/s. At this peak flux, the observed lunar sinuous rille system would have formed in 10–22 Earth days. This eruption flux is about two orders of magnitude higher than the investigated terrestrial eruptions. However, lunar eruptions are typically significantly larger than eruptions observed on Earth, as evident by the higher lava marks at the Rima Bode lava lake (60–80 m) relative to the Kilauea lava lake (2–4 m). In conclusion, by studying analogous terrestrial eruptions, we gained confidence in our interpretations that the morphology of sinuous rilles lend insight into lunar eruption dynamics.

References: [1] Hamilton et al. (2015) *LPSC 46*, #1072. [2] Gudmundsson et al. (2016) *Science*, 353. [3] Hurwitz et al., 2010, *Icarus*, 210, 626–634. [4] Hurwitz et al., 2012, *JGR-Planets*, 117, doi:10.1029/2011JE004000.